MATURITY CURVE METHOD OF DEVELOPMENT-CERTIFICATION

1. SCOPE

1.1. The following method covers the procedure for developing a maturity curve Time-Temperature-Factor (TTF) for concrete applications.

2. SUMMARY OF DETERMINATION OF CONCRETE MATURITY

2.1. Estimating the in-place concrete strength is a two step procedure:

- The first step is establishing a relationship between the maturity TTF and the concrete strength.
- The second step is the temperature monitoring of the placed concrete.

3. SIGNIFICANCE AND USE

3.1.The maturity TTF approach provides a simple and useful means of estimating the strength gain of concrete at early ages (generally less than 7 days). Its greatest benefit is that it allows engineers, inspectors and contractors to assess the in-place strength of concrete pavement or structure. This valuable information can then be used to help determine the appropriate time for opening pavement to traffic, sawing joints and stripping forms. It currently is used by NDOR for acceptance testing for pavement repairs and high early concrete.

4. EQUIPMENT NEEDED TO DEVELOP A MATURITY CURVE

4.1. Equipment needed to develop a curve.

- 4x8 cylinder molds with lids (10 min. - 14 max.)
- Scoop, rod and strike off
- Cure box, insulated blanket
- Type T thermocouple wire (24 gauge), mini connectors (blue), screwdriver, wire snips
- Maturity meter & plastic bag
- Concrete compression machine

5. PROCEDURE FOR DEVEOLOPING MATURITY CURVE

5.1. A maturity curve can be developed at the ready mix plant or on the project. The fresh concrete test will be performed by the project inspector. The air and slump shall meet the required specifications for the concrete mix. Since there is a relationship between the w/c ratio and strength, the concrete used to develop the maturity-strength relationship should be at or near the maximum w/c ratio expected during production.

5.2. Cast a minimum of ten (4 in. x 8 in.) concrete cylinders as per ASTM C 31.

5.3. Embed a thermocouple wire in two separate cylinders to monitor the temperature, in case one wire fails. Embed each wire at approximately mid-depth of the cylinder. These cylinders will not be tested for compressive strength.

5.4. Cure the cylinders accordingly at the test site to best represent the concrete placement. Cylinders cast for paving or structures may be cured in an insulated box, curing blankets, on grade, near the structure or in a trailer (Figure 1.). Cylinders cast for Pavement Repair (PR) and High Early (HE) concrete shall be cured in an insulated box until the time of compressive strength testing (Figure 2.).

Figure 1. Cylinders cast from paving

Figure 2. Cylinders cast from Patching

5.5. Immediately after the cylinders have been moved to their final location for curing there are two methods that can be used to calculate the TTF.

5.5.1. Maturity Meter

This is the preferred method for monitoring the concrete temperature. After the cylinders have been moved to their final location, connect the mini-connectors to Channel 1 (CH 1) and to Channel 2 (CH 2) on the maturity meter and start recording *(Maturity Meter datum temperature setting shall be set to -10 C)*. The age to test the first set of cylinders is determined from when the maturity meter was started and the initial temperature taken. Temperature reading will be in Celsius and rounded up to the next whole number. For your own documentation, record the initial temperature and the time it was taken. Cylinders for PR concrete may be moved 2.5 hours after casting. Cylinders for HE and Paving concrete may be moved 8 hours after the concrete has reached final set. For reference, the following are approximate ages when to perform compressive strength testing on your first set of cylinders;

- PR concrete may begin at three or four hours depending on the time of year and the type of cement used.
- HE concrete may begin at twelve to twenty-four hours.
- Paving concrete may begin at twenty-four hours.

The TTF is computed by the maturity meter. The TTF is read from the maturity meter at the same age the cylinders are tested for compressive strength. There is a correlation between the TTF and cylinder strength. The age of tests shall be spaced, so the cylinders tested are performed at somewhat consistent intervals. This data is then entered into the NDOR Maturity Method Form. (Appendix A-1)

5.5.2. Hand Calculated Method

An alternative method for monitoring the temperature of the concrete is by the digital hand held thermometer. Connect the mini connectors one at a time to a digital hand held thermometer and designate them as Channel 1 (CH 1) and Channel 2 (CH 2) then take the initial temperature. Record the time the initial temperature was taken for each designated channel. The temperature reading will be in Celsius and rounded up to the next whole number. This method of calculating the TTF by hand shall be performed at each age that a set of cylinders are tested. The Nurse-Saul Equation (Equation 1) is used by NDOR for calculating the TTF by hand calculation (Example 1) or by Field Data Spreadsheet (Figure 3). Both the TTF and cylinder strength will be reported in the NDOR Maturity Method Form (Appendix A-1).

$M(t) = \Sigma\,(T_a - T_o)\ \Delta t$
$M(t)$ = Time Temperature Factor (Maturity) at age Δt
T_a = Average temperature of the concrete during time interval Δt
T_o = Datum temperature (-10° C)
Δt = A time interval (Hours)

Equation 1. Nurse –Saul Equation

Example 1: The initial temperature of concrete is 20° C when placed, and 3 hours later it was 50° C.

- T_a = (20 + 50) / 2 = 35
- T_o = always add 10 to the average. When subtracting a negative number add it.
- Δt = elapsed time is 3 hours since the initial temperature was taken

M (TTF) = Σ (35 + 10) x 3
M (TTF) = **135**

The Field Data Spreadsheet (Figure 3) is a tool that can be used to generate the TTF. Enter the project information at the top of the spreadsheet then proceed to enter the date, time, age in hours and temperature. The spreadsheet will generate the Sum TTF by using the Nurse-Saul Equation. The sum TTF shall correspond with a set of cylinders at an age tested. This data will be reported in the NDOR Maturity Method Form (Appendix A-1).

MATURITY METHOD - FIELD DATA SHEET

EXAMPLE

Project : EACNH-30-5(121) Columbus East Maturity Curve #: 1
Control #: 32031 Contract #: Date Placed: 10/10/2001
Contractor: Mix: PR1-3500

Target TTF Value :

Section of Pavement to Open OR Structural Unit for Form Removal or Loading

From Station: To Station:

		Date	Time	Age (hours)	Temp (deg C)	TTF at age (deg C-hr)	Sum TTF (deg C-hr)	Air Temp (deg C)
Probe #	1	10/02/01	11:00 AM	0.00	21		0	
		10/02/01	01:00 PM	2.00	33	74	74	
		10/02/01	02:00 PM	3.00	42	47.5	122	
		10/02/01	03:00 PM	4.00	49	55.5	177	
		10/02/01	03:30 PM	4.50	53	30.5	208	
		10/02/01	04:00 PM	5.00	56	32.25	240	
		10/02/01	04:30 PM	5.50	57	33.25	273	
		10/02/01	05:00 PM	6.00	58	33.75	307	
						0	0	
						TTF:	307	

Figure 3. Field Data Spreadsheet - Link: located in the Appendix

6.0 STEPS FOR PLOTTING THE MATURITY CURVE

The following steps are for entering the data into the NDOR Maturity Method Form (Appendix A-1).

6.1 NDOR Maturity Method Form information.

6.1.1 Required Project information:

- Project number and description
- Control Number
- Contract Number
- Contractor performing the work
- Date maturity curve developed
- Curve number *(The curve number is identified for project use):
    - PR Concrete - Curve No.:
      1– Open (This will represent 3000 psi) Refer to Appendix A-2
      1– Acceptance (This will represent 3500 psi) Refer to Appendix A-3
    - Paving/HE - Curve No.:
      1– Acceptance (This will represent 3500 psi)
    - Structures - Curve No.:
      1– (This will represent the required strength)

(*) For each additional curve developed for a project, number the curves in ascending order.
For example; 2-Open, 3-Open, etc.

6.1.2 Required cylinders & TTF data entry

- Load at break (Total machine load in lbs)
- Length (in)
- Diameter (in)
- Age at break (Hrs)
- TTF CH 1 & TTF CH 2 (Values from maturity meter or hand calculated method)
- Cylinder Temperature Average (Not necessary to enter at every age)

6.1.3 Required Mix Information *

- Mix (Class of Concrete)
- Air (Percent)
- Method of Development (Curing method)
- DESIRED COMPRESSIVE STRENGTH (psi)**

(*) Additional mix information may be entered if available
(**) REQUIRED MINIMUM TTF (This corresponds with the desired compressive strength)

6.1.4 Required Comments

- Weather conditions
- Any pertinent information (Additional admixtures, water, etc)
- Enter sitemanager sample identification information

6.1.5 Signatures

- Certified Representative & Company Name - *Required*

6.2 Distribution of the developed Maturity Curve

After NDOR or Consultant have developed the maturity curve it is then submitted by email to the Project Engineer (PE), Field Inspectors and NDOR PCC Manager.

- PE and NDOR PCC Manager will place a copy of Maturity Curve in project file.

7.0 STEPS FOR VALIDATING MATURITY CURVE

7.1. Curve Validation

The validation tests shall be conducted to determine if the concrete strength is being represented by the current maturity curve. The following criteria and steps are for validating the maturity curve:

- Curve validation shall be performed approximately every 4 to 6 weeks during normal plant production. Validation is also needed when the original mix design changes and any time.

- NDOR PCC Manager or Consultant will schedule the validation date with the PE and Field Inspectors.
- The Field Inspectors will be requested to make five cylinders on the validation scheduled date.
- The Field Inspector will need to embed two thermocouple wires into two concrete cylinders.
- The certified personnel will request that the Field Inspector document the time the cylinders were cast and the initial temperature of the cylinders. This will be used to generate the TTF as stated in (5.5.1) or (5.5.2) in this document at the age requested.
- Cure the cylinders as stated in (5.4) of this document.
- Test three cylinders as close as possible to the Required Minimum TTF that is from the most current maturity curve being used.

7.1.1 Steps for Plotting Validation of Maturity Curve

The following steps are for entering the data into the NDOR Validation of the Maturity Curve – Compressive Strength Development Form. (Appendix A-4)

7.1.2 Required Project information:

- Project number and description
- Control Number
- Contract Number
- Contractor performing the work
- Date maturity curve developed
- Curve number *(The curve number is identified for project use):
    - *1– Validate*

(*) For each additional validation curve developed for a project, number the curves in ascending order. For example; 2-Validate, 3-Validate, etc.

7.1.3 Required Cylinders & TTF data entry

- Load at break (Total Machine load in lbs)
- Length (in)
- Diameter (in)
- Age at break (Hrs)
- TTF CH 1 & TTF CH 2 (Values from maturity meter (5.5.1) or hand calculated method (5.5.2))

7.1.4 Required Mix Information

- Mix (Class of Concrete)
- Air (Percent)
- Slump - *Not Required*
- METHOD OF DEVELOPMENT (Curing method)
- Maximum Difference Allowed (psi)

- PR and Paving Concrete: If the average calculated strength value at the TTF is within the range of $\pm$ 350 psi of the original curve, the original curve shall be validated. As shown in the Validation Curve graph and represented by the validation dot displayed between upper and lower limit. However:

  - If the average of the calculated strength value at the TTF falls below the Lower Limit represented by the Validation Curve graph a new curve *shall* be developed.
  - If the average of the calculated strength value at the TTF falls above the Upper Limit represented by the Validation Curve graph a new curve *may* be developed.

- Concrete Structures: The range will depend on the mix design strength. This may vary depending on the work performed. If the average calculated strength value at the TTF is within the range of $\pm$ 10% of the original curve, the original curve shall be validated, as shown in the Validation Curve graph and represented by the validation dot displayed between upper and lower limit. However:

  - If the average of the calculated strength value at the TTF falls below the Lower Limit represented by the Validation Curve graph a new curve *shall* be developed.

  - If the average of the calculated strength value at the TTF falls above the Upper Limit represented by the Validation Curve graph a new curve *may* be developed.

7.1.5 Required Comments
- Weather conditions
- Any pertinent information (Additional admixtures, water, etc)
- Enter sitemanager sample identification information

7.1.6 Signatures
- Certified Representative & Company Name - *Required*

7.1.7 Distribution of the developed Validation of Maturity Curve

After NDOR or Consultant have developed the maturity curve it is then submitted by email to the Project Engineer (PE), Field Inspectors and NDOR PCC Manager.
- PE and NDOR PCC Manager will place a copy of Maturity Curve in project file.

APPENDIX

Documents for Maturity Method can be found at the following Location: *FCAC\Forms\M&R Forms

*Consultants must have a LAN Account

Document Titles:

- *NDOR Maturity Method – Compressive Strength Development*
- *NDOR Validation of Maturity Curve – Compressive Strength Development*
- *Maturity Method - Field Data Spreadsheet*

Presentation for the Maturity Curve Method of Development can be found at the following location:
NDOR Website \ Materials & Research \ Training Videos & Tutorials\ M&R Division Presentations
http://www.transportation.nebraska.gov/mat-n-tests/divisionPresentations.htm

Document Title:

- *Presentation – Maturity Curve Method of Development*

NDOR MATURITY METHOD - COMPRESSIVE STRENGTH DEVELOPMENT

PROJECT: ______________________ CURVE NO.: ______________

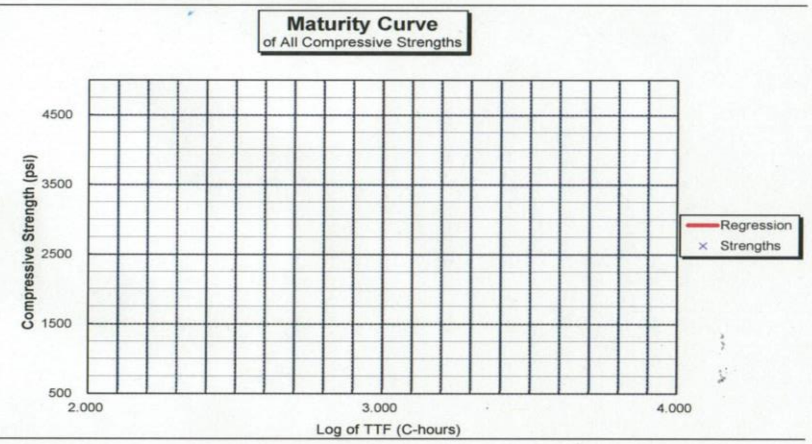
CON. NO.: ________ CONTRACT NO: ________ CONTRACTOR: ______________ DATE: ______________

Cylinder #	LOAD AT BREAK (lbs)	BREAK TYPE	Length (in)	Diameter (in)	Compressive STRENGTH (psi)	AGE AT BREAK (Hrs)	TTF CH 1	TTF CH 2	AVERAGE TTF	Cylinder TEMP (AVG)
	Enter		Enter	Enter		Enter	Enter	Enter		Enter
1									0	
2									0	
3									0	
4									0	
5									0	
6									0	
7									0	
8									0	
9									0	
10									0	
11									0	
12									0	

NDOR
Nebraska
Department of Roads

MIX INFORMATION	Enter
Mix:	
AIR:	
SLUMP:	
w/c:	
FLY ASH SOURCE:	
CEMENT SOURCE:	
COARSE AGGREGATE SOURCE:	
FINE AGGREGATE SOURCE:	
WATER REDUCER BRAND:	
Add. Rate:	
AIR ADMIXTURE BRAND:	
Add. Rate:	
METHOD OF DEVELOPMENT:	
DESIRED COMP. STRENGTH (psi):	psi

REQUIRED MINIMUM TTF: **#NUM!**



Certified Rep. & Company Name: ______________________
Signature

Certified Rep. & Company Name: ______________________
Signature

Comments:

cc: PM, Project Inspectors, NDOR District QAM, NDOR PCC Mgr.

Jan.2000,IowaDOT

NDOR MATURITY METHOD - COMPRESSIVE STRENGTH DEVELOPMENT

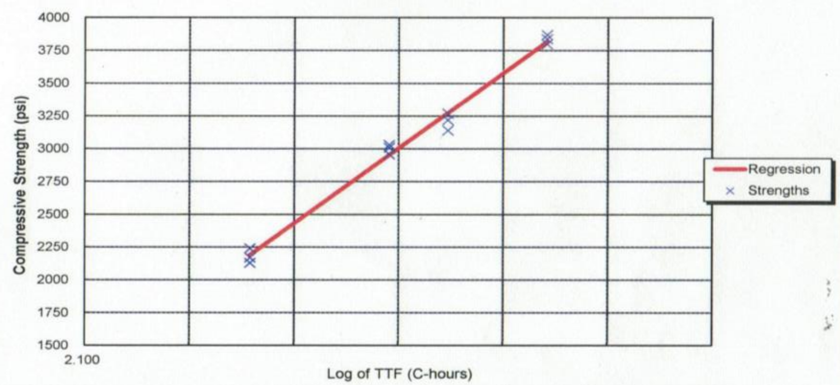
PROJECT: STPD-6-2(122) Culbertson to McCook **CURVE NO.:** 1-Open
CON. NO.: 70881 **CONTRACT NO:** 7881 **CONTRACTOR:** Ten Point **DATE:** 06/11/11

NDOR Nebraska Department of Roads Materials & Research

Cylinder #	LOAD AT BREAK (lbs)	BREAK TYPE	Length (in)	Diameter (in)	Compressive STRENGTH (psi)	AGE AT BREAK (Hrs)	TTF CH 1	TTF CH 2	AVERAGE TTF	Cylinder TEMP (AVG)
	Enter		Enter	Enter		Enter	Enter	Enter		Enter
1	27260		8.00	4.00	2170	4	181	181	181	53 C
2	26720		8.00	4.00	2130	4	181	181	181	
3	28110		8.00	4.00	2240	4	181	181	181	
4	37180		8.00	4.00	2960	5	246	246	246	
5	38070		8.00	4.00	3030	5	246	246	246	
6	37870		8.00	4.00	3010	5	246	246	246	
7	41040		8.00	4.00	3270	5.5	280	280	280	
8	40420		8.00	4.00	3220	5.5	280	280	280	
9	39470		8.00	4.00	3140	5.5	280	280	280	
10	47810		8.00	4.00	3800	6.5	348	348	348	58 C
11	48640		8.00	4.00	3870	6.5	348	348	348	
12	48225		8.00	4.00	3840	6.5	348	348	348	

MIX INFORMATION	Enter
Mix:	PR1 W/ Liquid Calcium
AIR:	6.4
SLUMP:	
w/c:	
FLY ASH SOURCE:	
CEMENT SOURCE:	
COARSE AGGREGATE SOURCE:	
FINE AGGREGATE SOURCE:	
WATER REDUCER BRAND:	
Add. Rate:	
AIR ADMIXTURE BRAND:	
Add. Rate:	
METHOD OF DEVELOPMENT:	Cylinders / Cure Box
DESIRED COMP. STRENGTH (psi):	3000 psi

REQUIRED MINIMUM TTF: 251



Comments: Weather - Approx 74 F for High.
Added Glenium 3030 on site.
See sitemanager entry for mix information.

Certified Rep. & Company Name: Tim A. Krason, NDOR
Signature

Certified Rep. & Company Name: ____________________
Signature

cc: PM, Project Inspectors, NDOR District QAM, NDOR PCC Mgr.

Jan.2000,IowaDOT

NDOR MATURITY METHOD - COMPRESSIVE STRENGTH DEVELOPMENT

PROJECT: STPD-6-2(122) Culbertson to McCook
CURVE NO.: 1-Acceptance
CON. NO.: 70881 **CONTRACT NO:** 7881 **CONTRACTOR:** Ten Point
DATE: 06/11/11

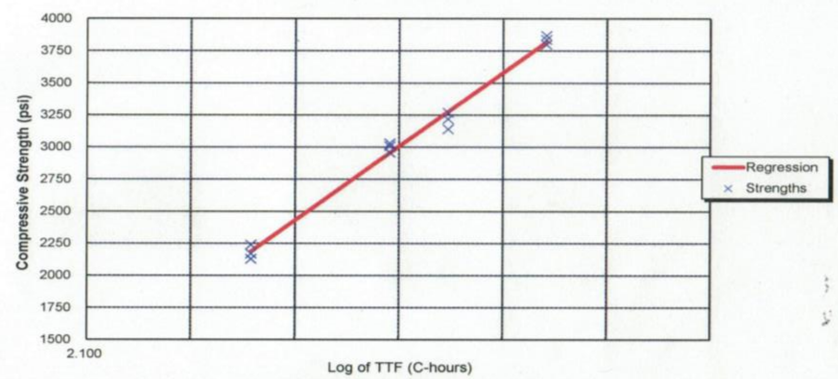
Cylinder #	LOAD AT BREAK (lbs)	BREAK TYPE	Length (in)	Diameter (in)	Compressive STRENGTH (psi)	AGE AT BREAK (Hrs)	TTF CH 1	TTF CH 2	AVERAGE TTF	Cylinder TEMP (AVG)
	Enter		Enter	Enter		Enter	Enter	Enter		Enter
1	27260		8.00	4.00	2170	4	181	181	181	53 C
2	26720		8.00	4.00	2130	4	181	181	181	
3	28110		8.00	4.00	2240	4	181	181	181	
4	37180		8.00	4.00	2960	5	246	246	246	
5	38070		8.00	4.00	3030	5	246	246	246	
6	37870		8.00	4.00	3010	5	246	246	246	
7	41040		8.00	4.00	3270	5.5	280	280	280	
8	40420		8.00	4.00	3220	5.5	280	280	280	
9	39470		8.00	4.00	3140	5.5	280	280	280	
10	47810		8.00	4.00	3800	6.5	348	348	348	58 C
11	48640		8.00	4.00	3870	6.5	348	348	348	
12	48225		8.00	4.00	3840	6.5	348	348	348	

NDOR Nebraska Department of Roads Materials & Research

MIX INFORMATION	Enter
Mix:	PR1 W/ Liquid Calcium
AIR:	6.4
SLUMP:	
w/c:	
FLY ASH SOURCE:	
CEMENT SOURCE:	
COARSE AGGREGATE SOURCE:	
FINE AGGREGATE SOURCE:	
WATER REDUCER BRAND:	
Add. Rate:	
AIR ADMIXTURE BRAND:	
Add. Rate:	
METHOD OF DEVELOPMENT:	Cylinders / Cure Box
DESIRED COMP. STRENGTH (psi):	3500 psi

REQUIRED MINIMUM TTF: 307

Maturity Curve
of All Compressive Strengths



Comments: Weather - Approx 74 F for High.
Added Glenium 3030 on site.
See sitemanager entry for mix information.

Certified Rep. & Company Name: Tim A. Krason, NDOR
Signature

Certified Rep. & Company Name: ____________________
Signature

cc: PM, Project Inspectors, NDOR District QAM, NDOR PCC Mgr.

Jan.2000,IowaDO

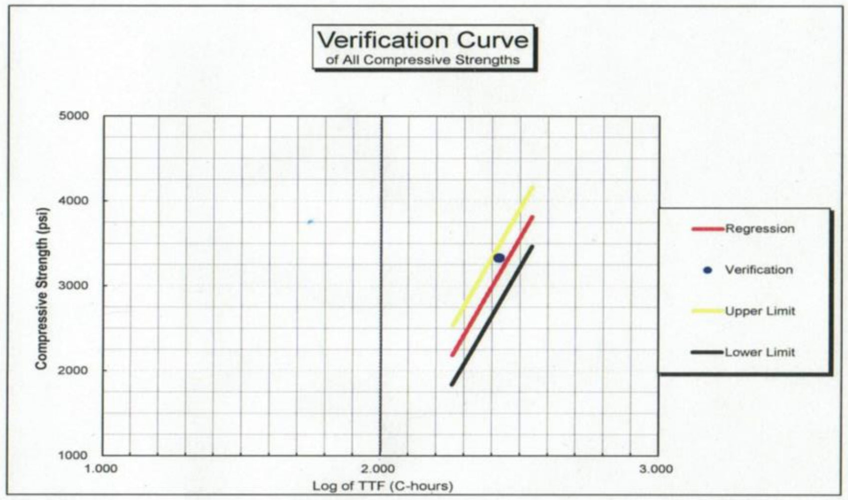
NDOR VERIFICATION OF MATURITY CURVE - COMPRESSIVE STRENGTH DEVELOPMENT

PROJECT: STPD-6-2(122) Culbertson to McCook
C.N.: 7881
CONTRACTOR: Ten Point
CURVE NO.: 1-Verify
DATE: 7/11/2011

CYLINDER #	LOAD AT BREAK (lbs)	BREAK TYPE (in)	Length (in)	Diameter (in)	Compressive STRENGTH (psi)	AGE AT BREAK (Hrs)	TTF CH 1	TTF CH 2	AVERAGE TTF
	Enter		Enter	Enter		Enter	Enter	Enter	
1	42120		8.00	4.00	3350	5	265	265	265
2	41600		8.00	4.00	3310	5	265	265	265
3	41880		8.00	4.00	3330	5	265	265	265

MIX: PR1 W/ Liquid Calcium Enter
AIR: 8 Enter
SLUMP: Enter
w/c:
FLY ASH:
CEMENT:
COARSE AGGREGATE:
FINE AGGREGATE:
WATER REDUCER:
Add. Rate:
AIR ENTRAINER:
Add. Rate:
METHOD OF DEVELOPMENT: Cylinders / Cure Box

CURVE VERIFICATION	
TTF @ Break	265
Cylinder 1 (psi)	3350
Cylinder 2 (psi)	3310
Cylinder 3 (psi)	3330
Avg. (psi)	3330



Maximum Difference Allowed (psi)			350
Calculated psi @ TTF	3137	Range Minimum	2787
		Maximum	3487

Curve Verification - OK

Comments:
See sitemanager entry for mix information.

It is ok to continue using the curve, it checked out above the lower limit.

Verification strength above the upper limit does not require a new curve.

Certified Rep. & Company Name: Tim A. Krason
Signature

Certified Rep. & Company Name: ____________
Signature

cc: PM, Project Inspectors, NDOR District QAM, NDOR PCC Mgr.

MATURITY.XLS
Jan.2000